Renewable and Sustainable Energy Reviews 14 (2010) 3005–3013

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Straight vegetable oils usage in a compression ignition engine—A review

R.D. Misra *, M.S. Murthy

Mechanical Engineering Department, National Institute of Technology, Silchar 788010, Assam, India

ARTICLE INFO

Article history:
Received 12 May 2010
Accepted 2 June 2010

Keywords:
Straight vegetable oils
Indian and international research work
Diesel engine performance
SWOT analysis

ABSTRACT

The ever increasing fossil fuel usage and cost, environmental concern has forced the world to look for alternatives. Straight vegetable oils in compression ignition engine are a ready solution available, however, with certain limitations and with some advantages as reported by many researchers. A comprehensive and critical review is presented specifically pertaining to straight vegetable oils usage in diesel engine. A detailed record of historical events described. Research carried out specifically under Indian conditions and international research work on the usage of straight vegetable oils in the diesel engine is separately reviewed. Many researchers have reported that straight vegetable oils in small percentage blends with diesel when used lower capacity diesel engines have shown great promise with regards to the thermal performance as well exhaust emissions. This has been explained in detail. Finally based on the review of international as well as Indian research a SWOT analysis is carried out. The review concludes that there is still scope for research in this area.

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Contents

1. Introduction

The Earth's limited reserves of fossil fuel have been a matter of global concern as these are under threat of depletion due to over exploitation. Deteriorating environmental conditions have become an issue of ever increasing worldwide public concern. Currently, the combustion of fossil fuels is the dominant global source of CO_2 emissions. There are efforts around the globe to protect the environment from further deterioration. These factors have led to an innovative global search for renewable sources of energy. Consequently, some alternatives, particularly renewable energy options have been discovered and explored. Several feasible technologies in the area of solar, wind, and biomass have been discovered, tested, perfected, and are increasing in popularity. Although majority of the renewable energy technologies are more eco-friendly than conventional energy options, their adoption is very slow because of various factors such as economic constraints, lack of supply, and technical know-how of users. Further the use of these technologies is still limited primarily to stationary operations, mainly due to technological limitations and poor economics. However biofuels are gaining popularity as they are immediate substitutes to the existing petro fuels. They require little engine modification or fuel modification. Generally biofuels are the oils obtained from the living plant sources. These oils may be obtained from resin and plant seeds. Plant oils are renewable and have low sulphur in nature. As the biofuels are more expensive than fossil

* Corresponding author. Tel.: +91 9435072301.
E-mail address: rdmisranit@gmail.com (R.D. Misra).

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doi:10.1016/j.rser.2010.06.010

fuels, the wide spread use of biofuel is restrained from its use in I.C. Engines [1,2]. The use of straight vegetable oil (SVO) in diesel engine has been identified well before the exploration of the other promising alternative fuel – alcohol.

The use of SVOs as a fuel for compression ignition engines is restricted by certain unfavorable properties, particularly their viscosity. This high viscosity results from the high molar masses of the oils and the presence of unsaturated fatty acids. At high temperatures there can be certain problems due to polymerization of unsaturated fatty acids. This occurs when cross-linking starts to occur between molecules, causing the formation of very large agglomerations and consequent gumming. The higher viscosities of SVOs cause poor fuel atomization, which leads to incomplete fuel combustion and carbon deposition on the injector and valve seat, resulting in serious engine fouling. When direct injection engines are run with SVOs, injectors become choked after a few hours. This choking also leads to poor fuel atomization and incomplete combustion. Due to incomplete combustion, partially burnt vegetable oil runs down the cylinder walls and dilutes the lubricating oil and thickens the lubricating oil. Despite the above-mentioned limitations of SVOs, it could be possible to use them for certain low-end applications, such as energizing the single cylinder diesel engines which are widely used in rural/agricultural applications. However, this would call for an additional fuel supply, since starting and stopping of the engine has to be done on diesel only to avoid deposition of neat oil on various engine parts, which would affect cold starting and performance of the engine. Also, the exhaust heat of the engine could be utilized to reduce the viscosity of the intake oil through an appropriate heat-exchanging device. Experiments conducted at various institutes have concluded that engines running on neat SVOs with the integration of above-mentioned additional sub-systems could perform effectively for around 250 h [1].

2. Historical background

It is very common for articles on biodiesel to start by claiming that Rudolph Diesel-fueled one of his early engines with peanut oil at the Paris Exhibition in 1900. For an excellent discussion of the history as it involved Rudolph Diesel, the authors suggest Knothe [3], who has prepared a comprehensive review of the literature available from the Diesel era, Knothe states that Diesel did not actually use peanut oil himself but was describing a test conducted by another company. In any case, the vegetable oil testing was considered to be a success and offered the potential for remote colonies to be self-sufficient in fuel. Knothe et al. [3], Quick [4], and others report that in a 1912 speech, Rudolf Diesel said "the use of vegetable oils for engine fuels may seem insignificant today, but such oils may become, in the course of time, as important as petroleum and the coal-tar products of the present time." The real interest in vegetable oil fuels began in the late 1970s during the OPEC oil embargo. A significant conference which documented the studies of the late 1970s was held in August 1982, under the auspices of the American Society of Agricultural Engineers (ASAE; now the American Society of Agricultural and Biological Engineers, ASABE). The conference was held in Fargo, North Dakota, and was entitled simply "Vegetable Oil Fuels". Contributions were made by leading researchers from around the world. While at that time the majority of the papers dealt with the potential of raw oils as fuel, several papers discussed the production of esters and the use of the esters as engine fuels that showed more promise than did the raw oils. Scientists from Brazil, the Republic of South Africa, the Northern Regional Research Center in Peoria, Illinois, the University of North Dakota, and Deere and Company all made presentations regarding the conversion of vegetable oil, primarily sunflower oil, to methyl esters. Aggarwal et al. reported that a 1952 review of research conducted in India, China, Belgium, and other countries concluded that "even with the existence of technical problems, vegetable oil as fuel showed promise" [5]. Borgelt et al. [6] also report interest in vegetable oils during World War II. Among these was a 1938 paper by John Walton in *Gas and Oil Power* entitled "The Fuel Possibilities of Vegetable Oils" followed by a 1942 paper by Seddon in the same journal entitled "Vegetable Oils in Commercial Vehicles". This was also cited in Baranescu and Lusco [7].

In the 1980s vegetable oils were considerably more expensive than diesel and it was mentioned that the additional processing would only drive the cost higher. The overall theme and outcome of the 1982 ASAE conference was that raw vegetable oils, while showing promise, had a tendency to cause injector coking, polymerization in the piston ring belt area causing stuck or broken piston rings, and a tendency to thicken lubricating oil causing sudden and catastrophic failure of the rod and/or crankshaft bearings. By 1983 the process to produce fuel quality engine-tested biodiesel was completed and published internationally [8]. An Austrian Company, Gaskoks, obtained the technology from the South African Agricultural Engineers and put up the first pilot plant for biodiesel in November 1987, and the erection of the first industrial biodiesel plant on 12 April 1989, with a capacity of 30,000 metric tonnes of rapeseed per year. Throughout the 1990s, plants were opened in many European countries, including the Czech Republic, France, Germany, and Sweden. At the same time, nations in other parts of world also saw local production of biodiesel starting up and by 1998 the Austrian Biofuels Institute identified 21 countries with commercial biodiesel projects. Two other important developments were the development of a 200-Hour Screening Test for Alternate Fuels [9] through joint efforts of Northern Agricultural Energy Center (NAEC; a subgroup of the USDA), engine manufacturers, and fuel additive suppliers, and a test to rapidly measure injector fouling in diesel engines [10]. Both of these tests encouraged uniformity in test methods and procedures. Schumacher et al. [11] described the earliest U.S. quality standard that has since then evolved into ASTM D 6751, which was approved in 2002. ASTM D 6751 is a standard for 100% biodiesel intended for blending with diesel. The industry is currently working on a standard for B20 (20% biodiesel–80% diesel) that they believe will be a major factor in obtaining favorable consideration of the engine manufacturers for use of B20. Biodiesel is never looking back and promising to be the future fuel.

3. The chemical composition of vegetable oils

All vegetable oils and animal fats consist primarily of triglycerides (also known as triacylglycerols). Triglycerides have a three-carbon backbone with a long hydrocarbon chain attached to each of the carbons. These chains are attached through an oxygen atom and a carbonyl carbon, which is a carbon atom that is double-bonded to second oxygen. The differences between oils from different sources relate to the length of the fatty acid chains attached to the backbone and the number of carbon–carbon double bonds on the chain. Most fatty acid chains from plant and animal based oils are 18 carbons long with between zero and three double bonds. Fatty acid chains without double bonds are said to be *saturated* and those with double bonds are *unsaturated*. Table 1 shows the amount of each of the five common fatty acid chains found in common oils and fats [12]. The presence of double bonds in the fatty acid chains has a dramatic effect on the properties of the methyl esters. The deformation of the molecule caused by the double bonds inhibits the growth of the crystals and this lowers the biodiesel's gel temperature. Saturated fats tend to gel at higher temperatures. Animal fats, hydrogenated vegetable oils, and some tropical oils such as palm oil and coconut

Table 1
Fatty acid composition for common oils and fats (% by weight).

	Palmitic acid	Stearic acid	Oleic acid	Linoleic acid	Linolenic acid
Number of carbons	16	18	18	18	18
Number of double bonds	0	0	1	2	3
Soybean	8	4	25	55	8
Canola (high oleic acid rapeseed)	4	2	60	22	12
High erucic acid rapeseed[a]	3	1	13	14	10
Mustard Oil[b]	4	2	24	21	10
Olive oil	10	2	78	10	trace
Palm oil	44	5	40	10	trace
Tallow[c]	28	22	42	4	trace
Lard	28	15	45	11	1
Yellow ease	20	18	54	8	trace

oil contain 35–45% saturated fatty acids and may be solid at room temperature. Biodiesel produced from these oils may gel at unacceptably high temperatures. The carbon–carbon double bonds in unsaturated oils and fats are prone to oxidation by oxygen in the air. This effect is magnified when the bonds are conjugated (two double bonds separated by two single bonds), as is the case for linoleic and linolenic acids. These fatty acids will oxidize 50–100 times faster than oleic acid with an unconjugated double bond [12]. Saturated fatty acids are not subject to this type of oxidative attack. The choice of oil or fat feedstock determines the resulting biodiesel's position in the trade-off between cold flow, oxidative stability, and cetane number. Biodiesel from more saturated feedstock will have higher cetane numbers and better oxidative stability, but will have poor cold flow properties. Biodiesel from oils with low levels of saturated fats will have better cold flow properties, but lower cetane number and oxidative stability [13,14].

4. Properties of various vegetable oils

The properties of various vegetable oils are listed in Table 2 [15]. It is seen that the cetane numbers are in the range of 37–42 showing that almost all vegetable oils shown here do not vary much. When compared with diesel these are about 28–15% lower than diesel. The kinematic viscosity of vegetable oil varies in the range of 30–40 cSt at 38 °C. The high viscosity of these oils is because of their large molecular mass in the range of 600–900. This is about 20 times higher than that of diesel fuel. The flash point of vegetable oil is very high (above 200 °C). The heating values are in the range of 39–40 MJ/kg, when compared to diesel fuel (about 45 MJ/kg), the vegetable oils are not far behind. The presence of chemically bound oxygen in vegetable oil lowers their heating values by about 10%. However its presence also helps in combustion process.

5. Indian developments

In an agricultural country like India, the use of vegetable oils in diesel engines has to be thoroughly investigated because of the possibility of large production capacity and producing it near the consumption points. At present, India is producing only 30% of the total petroleum fuels required. The remaining 70% is being imported, which costs about Rs. 80,000 crore every year. It is an astonishing fact that mixing of 5% biofuel to the present diesel fuel consumption in our country can save about Rs. 4000 crore every year. It is estimated that India will be able to produce 288 metric tonnes of biodiesel by the end of 2012, which will supplement 41.14% of the total demand of diesel fuel consumption in India. The planning commission of India has launched a biofuel project in 200 districts from 18 states in India. It has recommended two plant species, viz. Jatropha (*Jatropha curcas*) and karanja (*Pungamia pinnata*) for biodiesel production [16,17]. The recent auto fuel policy document states that biofuels are efficient, eco-friendly and 100% natural energy alternative to petroleum fuels [18].

Among the many species, which can yield oil as a source of energy in the form of biofuel, *Pongamia pinnata* has been found to be one of the most suitable species in India being widely grown, it is N_2-fixing trace, not brought by animals and oil is non-edible. The trees are tolerant to water logging, saline and alkaline soils; they can withstand harsh climates (medium to high rainfall). It can be planted on degraded lands, farmer's field boundaries, wastelands/fallow lands and could be grown across the country. Powerguda, a small village in the state of Andhra Pradesh, in India became an environmental pioneer by planting *Pongamia* seedlings and when it sold the equivalent of 147 tonnes of carbon dioxide in verified emission reduction to the World Bank to neutralize the emissions from air travel and local transport by the participants of international conference held in Washington from 19 to 21 October 2003, the World Bank paid US$ 645 to Powerguda women self-help groups.

Table 2
Properties of vegetable oils.

Vegetable oil	Kinematic viscosity at 38 °C (mm^2/S)	Cetane no.	Heating value (MJ/kg)	Cloud point (°C)	Pour point (°C)	Flash point (°C)	Density (kg/l)
Com	34.9	37.6	39.5	−1.1	−40	277	0.9095
Cottonseed	33.5	41.8	39.5	1.7	−15	234	0.9148
Crambe	53.6	44.6	40.5	10	−12.2	274	0.9048
Linseed	27.2	34.6	39.3	1.7	−15	241	0.9236
Peanut	39.6	41.8	39.8	12.8	−6.7	271	0.9026
Rapeseed	37	37.6	39.7	−3.9	−31.7	246	0.9115
Safflower	31.3	41.3	39.5	18.3	−6.7	260	0.9144
Sesame	35.5	40.2	39.3	−3.9	−9.4	260	0.9133
Soya bean	32.6	37.9	39.6	−3.9	−12.2	254	0.9138
Sunflower	33.9	37.1	39.6	7.2	−15	274	0.9161
Palm	39.6	42		31	–	267	0.918
Babassu	30.3	38	–	20	–	150	0.946
Diesel	3.06	50	43.8	–	−16	76	0.855

5.1. Indian research

Prasad et al. conducted tests with a low heat rejection diesel (LHR) engine showed that the use of pure JCL oil results in a higher brake specific energy consumption (BSEC), lower brake thermal efficiency (BTE), higher exhaust gas temperature (EGT) and lower NO_x emissions in comparison with fossil diesel [19]. Preheating and increasing the injection pressure decreased BSEC, increased BTE, increased EGT and increased NO_x emissions only marginally. Kumar et al. [20] compared the use of JCL oil and fossil diesel in a single cylinder four-stroke water-cooled diesel engine and concluded that the soot (hydrocarbon) emission is higher with JCL oil as compared to fossil diesel. At maximum output an increase from 100 ppm, for fossil diesel, to 130 ppm, for JCL oil, was measured and similar trends were observed in the case of CO emissions. Smoke level was higher with JCL oil (4.4 BSU) compared to fossil diesel (3.8 BSU) as well. Furthermore they observed an increase in ignition delay and combustion duration with JCL oil in comparison to fossil diesel.

Rao and Goapalkrishnan [21] evaluated the performance of a diesel engine with vegetable oils and methyl esters of karanja oil, soybean oil, sunflower oil, and neem oil. The brake thermal efficiency (BTE) of the engine was reported to be less with vegetable oils and methyl esters of different vegetable oils as compared to diesel. The exhaust smoke intensity was also found to be more with vegetable oils and their methyl esters compared to diesel fuel. It was observed that the combustion delay for all the vegetable oils used was higher than that of diesel by 1–2° CA at full load and the highest ignition delay was observed with neem. However, the ignition delay was shorter for the methyl esters compared to vegetable oils. Reddy and Ramesh in their experiments on Jatropa oil-fuelled compression ignition engine showed that retarding the injection timing with enhanced injection rate of a single cylinder, constant speed, direct injection diesel engine, operating on neat JCL oil, showed to improve the engine performance and emission level significantly [22]. The measured emissions were even lower than fossil diesel. At full output HC emission level was observed to be 532 ppm against 798 ppm for fossil diesel, NO_x level was 1163 ppm against 1760 ppm and smoke was reduced to 2.0 BSU against 2.7 BSU. However, the achieved BTE with JCL oil (28.9%) was lower than with fossil diesel (32.1%) [22].

Bajpai et al. [23] conducted tests on a single cylinder constant speed (1500 rpm) diesel engine having compression ratio 17.5, as widely used in rural/agricultural applications. The fuels studied were mineral diesel and blends of karanja vegetable oil (KVO) with mineral diesel. The results are very promising especially in the case of Indian scenario. They concluded that petroleum diesel blended with 10% neat karanja oil (KV10) can be adopted as an alternative fuel for existing conventional diesel engines without any major hardware modifications. Preheating of KVO is a process that brings about a change in the molecular structure of the vegetable oil molecules, thus bringing down the viscosity. The viscosity of the preheated neat karanja oil at 90 °C was found to be very close to that of petroleum diesel oil. The flash point of KVO and its blends was higher than that of diesel oil, which signifies a safe range for storage of KVO. All these tests for the characterization of KVO demonstrated that almost all the important properties of KVO were in very close agreement with diesel oil, thus making it a potential fuel for application in compression ignition engines as a partial replacement for diesel fuel. KVO10 was found to be the best, among all the blends of KVO5, KVO10, KVO15 and KVO20. KVO10 showed improved thermal efficiency of the engine. Similarly, the brake specific fuel consumption (BSEC) and exhaust emissions were also reduced appreciably. Decreases in the exhaust gas temperature of a KVO-fueled engine led to an approximately 4% decrease in NO_x emissions for KVO10. The performance of the KVO-fueled engine was marginally better than the diesel-fueled engine in terms of thermal efficiency, BSEC, smoke opacity and exhaust emissions, including NO_x emission, for the entire range of operations. It was conclusively demonstrated that the self-lubricity and oxygen content of KVO played a key role in engine performance. Fuel preheating and exhaust gas recirculation is recommended for the diesel engine to be operated with optimum test fuels. Injection timing and duration may also be changed for better combustion of high viscosity vegetable oil. The experimental results of Bajpai et al. [23] are as shown below.

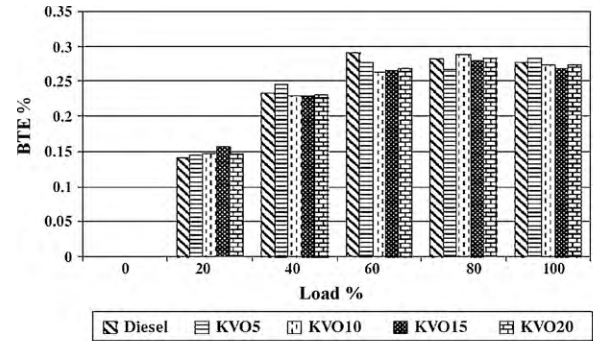


Fig. 1. Comparative plot of brake thermal efficiency vs. % load.

It is clearly seen from Fig. 1 that BTE is better for KVO at lower loads; even at higher loads lower percentage of KVO blends outperform diesel.

From Fig. 2 it is observed that BSEC is slightly higher for neat diesel at lower loads and remained same for KVO5, KVO10, KVO15, and KVO20.

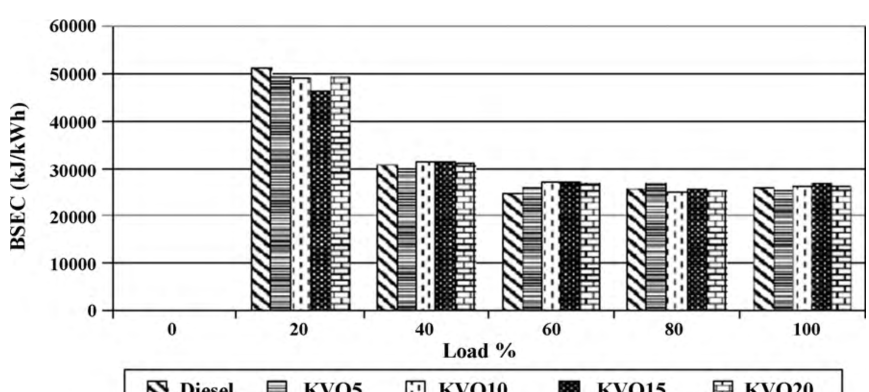


Fig. 2. Comparative plot of brake specific energy consumption vs. % load.

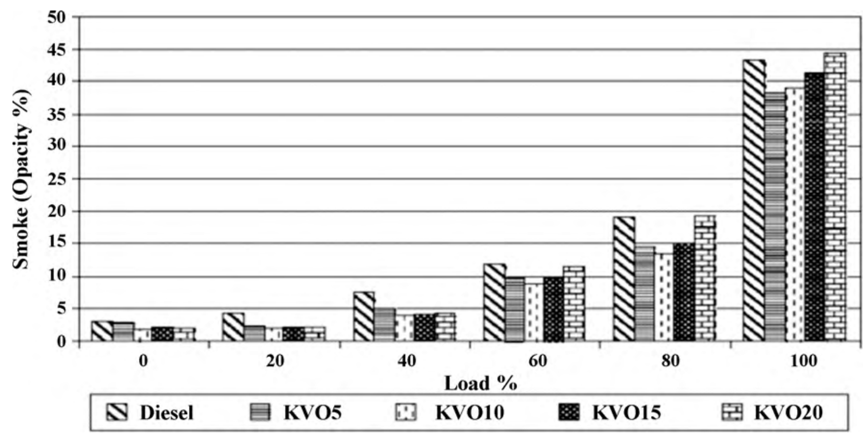


Fig. 3. Smoke (opacity %) at different loads.

Fig. 3 clearly indicates smoke is significantly less for all blends. This is because of complete and stable combustion. The opacity is least for KVO10 at up to 80% load where normally the manufacturers of diesel engines recommend operating.

Fig. 4 shows that NO_x emissions are lower for all blends. The lower NO_x emission could be because of lower exhaust temperature. NO_x emission at 100% load for KVO blends are lower than mineral diesel.

Fig. 5 shows that KVO10 has less HC emissions up to a load of 60%. However HC emission is more at higher loads for all blends.

Fig. 6 clearly shows that CO emission was lower for the entire range of loads for KVO5, KVO10, KVO15. However KVO20 is not recommended as far as CO emission is considered as it shows higher CO emission.

Another experimental results are analyzed here for further understanding. Devan and Mahalakshmi [24] conducted tests using neat poon oil (*Sterculia foetida*) and its blends with petroleum diesel on a single cylinder four-stroke air-cooled diesel engine developing 4.4 kW at 1500 rpm. They concluded that the engine power output and fuel consumption of the engine are almost the same when the engine is fueled with lower poon oil–diesel blends compared with those of standard diesel. As can be seen from Fig. 7 the emissions of oxides of nitrogen (NO_x) from Neat poon oil and its diesel blends are lower than those of standard diesel fuel. From the emission analysis it was observed, that there was a 32% reduction

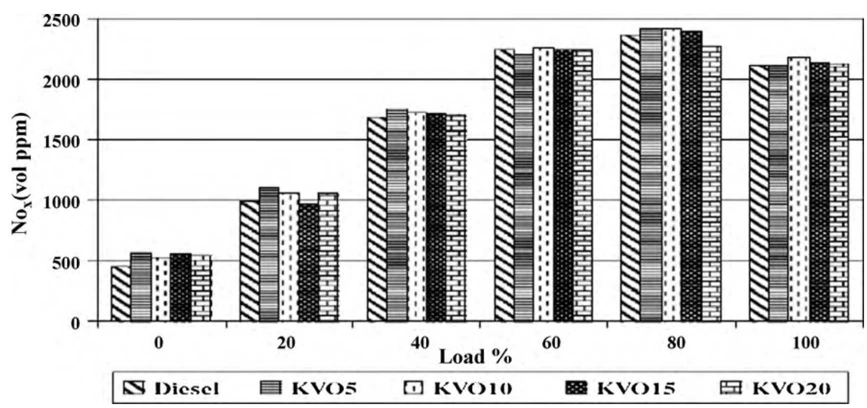


Fig. 4. NO_x emission at different loads.

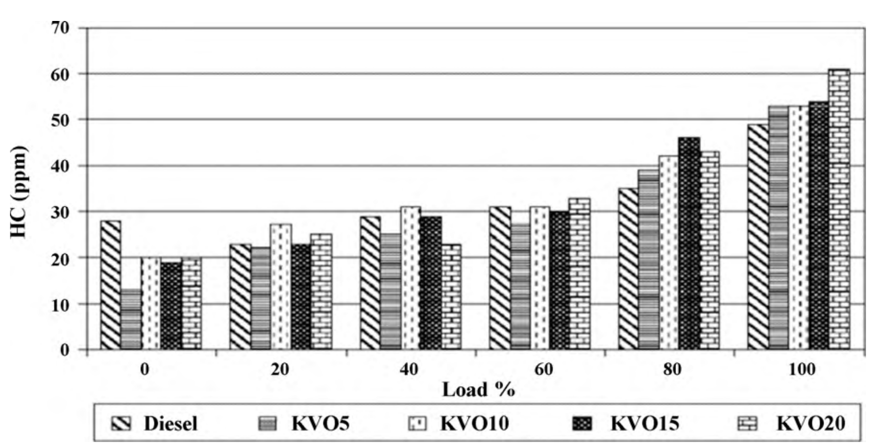


Fig. 5. Emission of unburnt hydrocarbons at different loads.

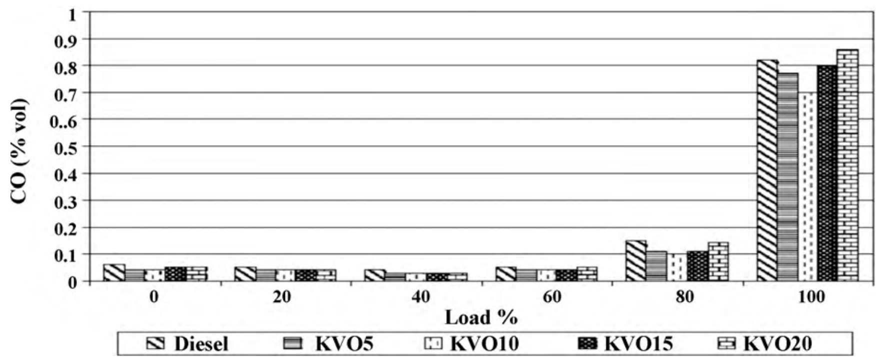


Fig. 6. Carbon monoxide emission at different loads.

in NO_x emission for Neat poon oil and 4% reduction for Neat 20 blend. The carbon monoxide (CO) emissions, as shown in Fig. 8, from Neat poon oil and its diesel blends were higher except in the case of the Neat 20 blend where it was reduced by 12%. However, there was an increase in CO emission for Neat poon oil by 35% at full load. From Fig. 9 it can be seen that the hydrocarbon (HC) emissions of poon oil and its diesel blends are slightly higher than those of diesel fuel except in the case of the Neat 20 blend. There was an increase in hydrocarbon emission by 18% in the case of Neat poon oil whereas 14% reduction was observed in the case of the Neat 20 blend at full load. The results from the experiments prove that lower poon oil–diesel blends are potentially good substitute fuels for diesel engines.

From the above two experiments it is very clear that there is still scope for running diesel engines on lower percentage blends of straight vegetable oils especially for smaller engines suitable for agricultural purposes and small power generating sets which are sold in large numbers in an agriculture dominated country like India.

6. International developments

Global vegetable oil production increased from 56 million tonnes in 1990 to 88 million tonnes in 2000 [25]. More than 350 oil-bearing crops have been identified, of which only soybean, palm, sunflower, safflower, cottonseed, rapeseed, and peanut oils are considered potential alternative fuels for diesel engines [26,27]. Various oils have been in use in different countries as raw materials for biodiesel production owing to its availability. Soybean oil is commonly used in United States and rapeseed oil is used in many European countries for biodiesel production, whereas, coconut oil and palm oils are used in Malaysia and Indonesia for biodiesel production [28–31]. In India and Southeast Asia, the Jatropha (*Jatropha cursas*) [32], Karanja (*Pongamia pinnata*) [29,33,34] and Mahua (*M. indica*) are used as a significant fuel source.

6.1. International research

The main advantages of vegetable oils as diesel fuel are ready availability, renewability, lower sulphur and aromatic content, and biodegradability [26]. The main disadvantages of vegetable oils as diesel fuel are higher viscosity, lower volatility, and the reactivity of unsaturated hydrocarbon chains. The problems met in long-term engine tests, according to results obtained by earlier researchers, may be classified as follows: coking on injectors, valve seats [35,36] more carbon deposits, oil ring sticking, and thickening and gelling of the engine lubricant oil, [37–40]. Vegetable oils can be used as fuels for diesel engines and these oils are extremely viscous, with viscosities ranging from 10 to 17 times greater than diesel fuel with 10–20 carbon number hydrocarbons [41–43]. Different methods have been considered to reduce the viscosity of vegetable oils such as heating, dilution, micro-emulsification, pyrolysis, catalytic cracking and transesterification. As the oil temperature increases its viscosity decreases [44]. The lower the viscosity of the biodiesel, the easier it is to pump and atomize and achieve finer droplets [45].

Ziejewski et al. in their experiment blended 25% sunflower oil and 75% diesel and used it as a diesel and used in diesel. They concluded that dilution of vegetable oils with solvents lowers the viscosity. By this way some engine performance problems such as injector coking and more carbon deposits could be addressed [46]. Another study was conducted by using the dilution technique on the same frying oil by Karaosmonoglu [47]. The viscosity of oil can be lowered by blending with pure ethanol. Bilgir et al. studied the effect of diesel–

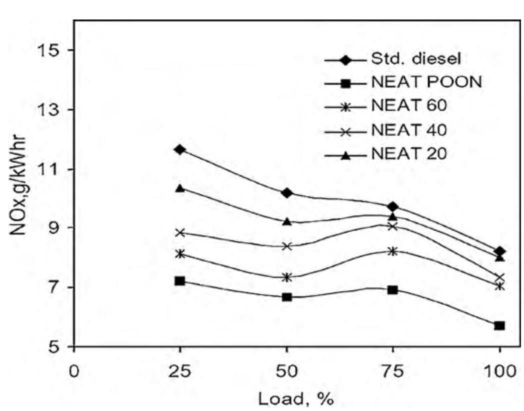


Fig. 7. Variation of NO_x with load with different blends.

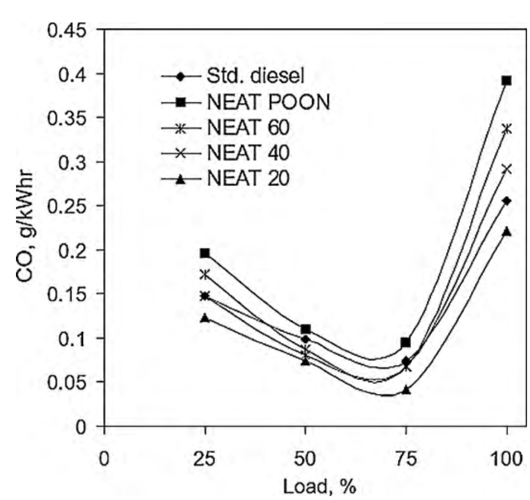


Fig. 8. Variation of CO with load with different blends.

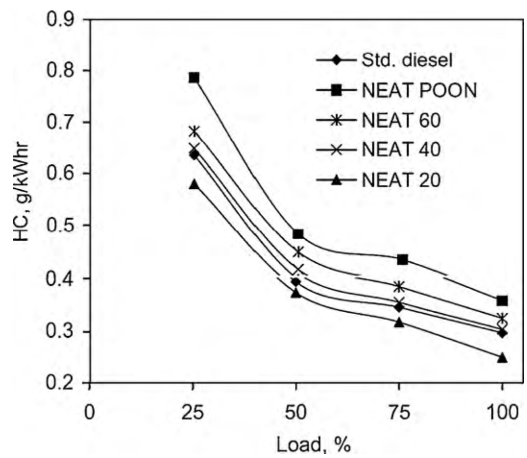


Fig. 9. Variation of HC with load with different blends.

ethanol blends on diesel engine performance. They suggested that addition of 4% ethanol to No. 2 diesel fuel increases the brake thermal efficiency, brake torque and brake power, while decreasing the brake specific fuel consumption. The high combustion temperature at high engine speed becomes the dominant factor, making both heated and unheated fuel to acquire the same temperature before fuel injection [48]. Various methods of using vegetable oil (Jatropha oil) and methanol such as blending, transesterification and dual fuel operation were studied experimentally [49]. Brake thermal efficiency was 27.4% with neat Jatropha oil to a maximum of 29% with the methyl ester and 28.7% in the dual fuel operation [49]. This shows that the neat Jatropa oil is not far in thermal efficiency than the esterified or dual fuel operation. Wang et al. from their experimental investigation of the performance and gaseous exhaust emissions of a diesel engine using blends of a vegetable oil concluded that the blending method has the advantages of improving the use of vegetable oil fuel with the minimal fuel processing and engine modification [50]. Several other experiments have also come to similar conclusions. The diesel engine would run successfully – without any modification and without damage to engine parts – on various blends of vegetable oil and diesel fuel [51–53]. A comparison of engine performance and emissions of diesel fuel with those of vegetable oil and its diesel blends showed lower thermal efficiency, lower NO_x and higher CO and HC emissions [54–56]. The engine performance with biodiesel and vegetable oil blends of various origins was evaluated by Rakopoulos et al. who concluded that it was similar to that of neat diesel fuel with nearly the same brake thermal efficiency [57]. The engine power and torque of the mixtures of vegetable oil–diesel fuel are close to the values obtained from diesel fuel and the amounts of exhaust emissions are lower than those of diesel fuel as reported by Altun et al. [58]. Forson et al. in their experiment on performance of Jatropha oil blends in a single cylinder, air-cooled, direct injection, four-stroke diesel engine showed that a blend of 2.6% of Jatropa oil and 97.4% fossil diesel by volume showed lowest BSFC and highest BTE [59] in comparison to fossil diesel and blends with higher JCL oil portion. In the oil extraction procedure of the used JCL oil a small portion of water was added which emulsified the JCL oil. This resulted in a reduction of EGT and, as such, a reduction in NO_x emission with increasing portion of JCL oil in the blend.

7. SWOT analysis of vegetable oils usage in C.I. Engine

A strength–weakness–opportunities–threat (SWOT) analysis of vegetable oil usage in compression ignition is carried out based on the review of research work being done both in India and across the world.

Strengths

- It is a renewable energy source.
- It balances carbon dioxide in environment or can be said as CO_2 neutral to environment.
- Like all trees, oil seeds borne trees also remove carbon from the atmosphere, stores it in the woody tissues and assists in the buildup of soil carbon. It is thus environment friendly.
- The fuel production technology is simple and proven.
- Number of non-edible oil crops is perennial and are not affected by climatic changes.
- Cetane number is similar or close to that of diesel fuel.
- Heating values of various vegetable oils are nearly 90% to those of diesel fuel.
- Higher flash point allows it be stored at high temperatures without any fire hazard.
- At lower percentages of vegetable oil blends with diesel have shown better results than the fossil diesel in terms of engine performance and exhaust emissions.
- Additional oxygen molecule in its chemical structure helps in combustion process.
- They seldom contain sulphur which is a major problem with fossil fuels.
- NO_x emissions are drastically less up to around 30% for 100% straight vegetable oil.
- Straight vegetable oils are available normally in rural area where its usage is advantageous especially in smaller engines in agricultural sector.
- Improve the living conditions of the rural people and offer greater income opportunities through enhanced rural employment.
- Various researchers have shown that the use of vegetable oil and their derivatives is economical and competitive compared to mineral diesel.
- Plant leafs and deoiled cake can be used as organic manure which can be source of additional income farmers.

Weaknesses

- The vegetable oils in their natural form have higher viscosity compared to diesel.
- Variable output, variable oil content, long gestation period of crop.
- At present the availability is widespread and scattered.
- No large scale production plants.
- The presence of chemically bound oxygen in vegetable oil lowers their heating values.
- High viscosity of vegetable oil interferes with the injection process and leads to poor fuel atomization.
- Lube oil dilution, high carbon deposits, ring sticking, scuffing of the engine liner, injection nozzle failure are the major problems associated with direct use of straight vegetable oils.
- The high flash point attributes to lower volatility characteristics.
- Both cloud and pour points are significantly higher than that of diesel fuel. These high values may cause problems during cold weather.
- Long storage problems as the viscosity gets further high on long storage.
- No commercial output available without ample farming inputs.
- Land or acreage required for commercial production is vast and feasible in cooperative farming.

Opportunities

- Ever increasing crude oil price.
- There are number of non-edible oils which are good fuels. About 300 varieties tree born oil seeds have been identified.

- Better utilization of cultivable wasteland. Selected crops can be grown on arid and semi-arid lands which are presently not cultivable.
- Vegetative propagation possible in many varieties.
- Having carbon credit value (Kyoto protocol).
- There is huge demand worldwide owing to environmental problems.
- With use of Biotechnology encouraging primary results are obtained with regards to seed yields.
- Diesel fuel dissolves quite well with vegetable oils.
- Preheating, blending of vegetable oils with diesel fuel, blending vegetable oils with solvents would solve many problems associated with diesel engine operation with neat vegetable oil.
- Many researchers have shown that lower levels of straight vegetable oil blending with diesel exceeded the performance of diesel. Hence many researchers recommend further research on this.
- A great opportunity for reduction of NO_x which has been posing a threat to the survival of diesel engine.
- It has great potential of employment generation capacity in rural areas. According to an estimate at 5% biodiesel blending India would produce 200 million jobs equal to all jobs in U.S.A. and U.K.

Threats

- No tried and tested cultivation experiences on mass scale.
- The behavior of the plants is varied in different agro climatic zones as well as regions. Hence it shall be daring to give monotonous verdict in favor of them for all climatic zones.
- It is still to be established how these plants would behave once it is removed from its original habitat and put under high density and intensive cropping system.
- No economic viability for mono crop.
- Over publicity.
- Abundance of misleading information among the uneducated farmers.
- Costly input materials at present.
- As of now these oils are difficult to sustain economically without subsidies.
- No sustainable procurement mechanism available in the market.
- Requirement of seeds in large quantity even to fulfill demand of 5% blending with diesel.
- Indiscriminate cutting of forests for tree borne oil crops cultivation may pose threat to the biodiversity as palm oil plantations in Malaysia destroying orangutan habitat.

8. Conclusions

From the above-summarized studies it can be concluded that the usage of pure vegetable oil, straight or in a blend with fossil diesel, in a compression ignition engine cannot be underrated. Certainly in tropical developing countries like India the use of pure vegetable oil, straight or as a blend, is believed to have great potential. The diesel engines in these countries are easier to adapt to the characteristics of these fuels as the tropical temperatures lower the viscosity of the oil. Stationary diesel engines running at low speed, such as irrigation pumps and electricity generators, are believed to be suitable to pure vegetable oil and their blends without a too high environmental burden. Pre-chamber diesel engines are more suitable for the use of pure oil than direct injection engines, but simple conversion to a direct injection engines two-tank system can overcome their problems. Preheating of the fuel by exhaust gases could be one feasible solution to overcome the problem of high viscosity – being the major cause of many a problems identified several researchers. Straight vegetable oils have the potential to reduce NO_x emissions which is one of the major concerns of the world today. The review conclusively establishes that straight vegetables and their blends still hold a lot of promise as regards to their usage in compression ignition engines. Further research can be taken up in this field.

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